Experiences with Testing the Largest Ground System NASA Has Ever Built

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Abstract

In the 1980s, the National Aeronautics and Space Administration (NASA) embarked upon a major Earth-focused program called Mission to Planet Earth. The Goddard Space Flight Center (GSFC) was selected to manage and develop a key component--the Earth Observing System (EOS). The EOS consisted of four major missions designed to monitor the Earth. The missions included 4 spacecraft: Terra (launched December 1999), Aqua (launched May 2002), ICESat (Ice, Cloud, and Land Elevation Satellite, launched January 2003), and Aura (scheduled for launch January 2004). The purpose of these missions was to provide support for NASA's long-term research effort for determining how human-induced and natural changes affect our global environment.

The EOS Data and Information System (EOSDIS), a globally distributed, large-scale scientific system, was built to support EOS. Its primary function is to capture, collect, process, and distribute the most voluminous set of remotely sensed scientific data to date estimated to be 350 Gbytes per day. The EOSDIS is composed of a diverse set of elements with functional capabilities that require the implementation of a complex set of computers, high-speed networks, mission-unique equipment, and associated Information Technology (IT) software along with mission-specific software.

All missions are constrained by schedule, budget, and staffing resources, and rigorous testing has been shown to be critical to the success of each mission. This paper addresses the challenges associated with the planning, test definition, resource scheduling, execution, and discrepancy reporting involved in the mission readiness testing of a ground system on the scale of EOSDIS. The size and complexity of the mission systems supporting the Aqua flight operations, for example, combined with the limited resources available, prompted the project to challenge the prevailing testing culture. The resulting success of the Aqua Mission Readiness Testing (MRT) program was due in no small measure to re-structuring the traditional programmatic and technical approach to a more efficient and robust program. Programmatically, it meant gaining the endorsement, commitment, and cooperation of the numerous subsystem element managers and other stakeholder organizations. Technically, it required an MRT program that was agile, could rapidly adapt to requirements changes, and was flexible in its overall approach. Furthermore, this paper addresses the following questions:

1) *What are the key "ingredients" (e.g., test tools, organization) needed to conduct a successful MRT program?*
2) *What distinguishes EOS MRT from the traditional system testing approach?*
3) *Where should the focus of testing be since it is infeasible to test every element or subsystem?*
4) *How can MRT be applied effectively to other systems or missions?*

To provide answers to these questions, this paper relies heavily on real-life, hands-on experiences ("lessons learned") gained during mission readiness testing of the Terra ground system and, most recently, the Aqua and ICESat missions. Moreover, this paper explores how lessons learned were turned into "lessons applied" for the upcoming Aura mission. Although derived from the EOS missions, MRT techniques and strategies can be applied to enhance the testing of other missions.

1. Introduction

With the recent successes of the Terra, Aqua, and ICESat missions (and Aura scheduled for launch in early 2004), NASA's Earth Science Enterprise will soon be realizing its vision of having a fleet of Earth-observing platforms continuously "taking the pulse" of the Earth and its environs in an effort to improve prediction of weather, climate, and natural hazards using the unique vantage point of space. To accomplish this feat, the Earth Observing System (EOS) was conceived in the 1980's; the Goddard Space Flight Center was selected to design, implement, manage, and operate the EOS over its lifetime. Over the past ten years, the EOS has evolved and matured in phases and was finally commissioned in December 1999 with the successful launch of the Terra spacecraft.

The EOS linchpin, the EOS Data and Information System (EOSDIS) was envisioned to support the estimated 350 billion bytes per day of Level-0 science data that will be generated from the four EOS spacecraft. The EOSDIS consists of a diverse set of integrated elements with functional capabilities that required the implementation of a complex set of computers, high-speed networks, mission-unique equipment, and associated Information Technology software. EOSDIS capabilities include the processing of all data flows for the four EOS missions, from the flight operations control center that manages the health and safety of the spacecraft, to the extensive distributed systems that provide science data processing, archive, and distribution services. The EOSDIS is an integrated part of the EOS Ground System (EGS), which includes NASA institutional capabilities such as the Space and Ground Networks for satellite communications, the EOS Mission Support and Science Support networks, and the Flight Dynamics Facility. Complete and effective testing of this large and distributed ground system is vital to the success of the EOS missions. In order to ensure mission success, EOSDIS management chartered a mission readiness test team under the direction of a Mission Readiness Manager (MRM). The ground system supporting each of the four missions would be thoroughly tested from a mission operations perspective along with all of its associated Ground Network (GN) and Space Network (SN) assets.

The initial concept for a comprehensive EOS mission readiness test program, conducted by an independent test team, was applied to the first mission, Terra. However, because of significant problems with the original EOS Operations Center (EOC) architecture (e.g., real-time performance, software delays), along with associated launch schedule pressures, the original plan was abandoned, and all mission readiness testing was conducted in conjunction with the Flight Operations Team (FOT). Although solving the immediate schedule pressures, the overall testing effort did not achieve the desired confidence in ground system performance. It was concluded that the model previously used on small Goddard missions, in which the flight operations team controlled the ground system test program, was not adequate for large missions like Terra and Aqua, which required a large FOT, complex mission scheduling, and ingest of large volumes of science data. For the upcoming Aqua mission, senior management challenged the Aqua MRM to develop a more effective mission readiness testing model. After a thorough review of how testing was conducted for the Terra mission (see "Lessons Learned from the Terra Testing Experience"), the decision was made to "re-architect" the overall Mission Readiness Test (MRT) program. Refer to Table 1 for the major features incorporated into the revised model. Employing a combination of best system engineering practices and program management skills, we successfully implemented this new model for the remaining EOS missions. The remainder of this paper will discuss how this new model enabled us to test successfully NASA's largest ground system.

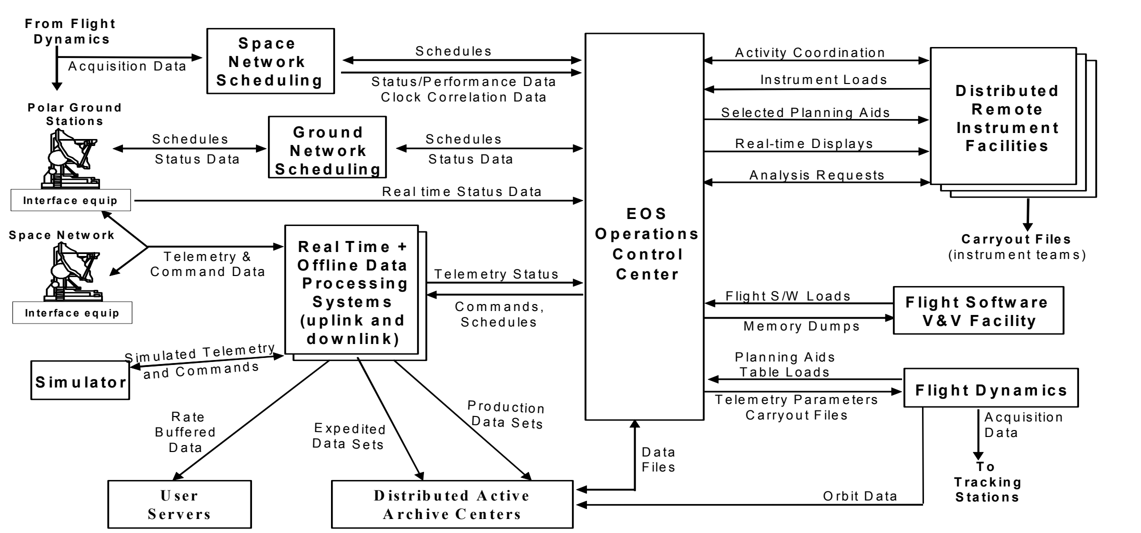

Figure 1. EOS Ground System

2. Lessons Learned from the Terra Testing Experience

The Terra mission was the first in the planned series of EOS spacecraft. The spacecraft and ground system elements were new and complex, requiring extensive development resources. Numerous development problems for the many first-generation systems had to be resolved, and the test engineers had to learn about the architecture and planned capabilities of the ground system as they evolved.

The requirements against which the mission readiness testing was conducted were not originally developed to be a requirement set; rather, they were a compilation of functionality to capture the current ground system design. Due to time constraints with launch scheduled less than 7 months away (launch occurred 12 months later), no requirement analysis or improvement was performed. As a result, the test team labored to test and verify them as written. For example, individual requirements often specified multiple functions and were very difficult to provide a status within one test event. Many requirements ended up with 'Partial Pass' statuses that were never completed. However, the set of requirements was useful in that it did derive from valid sources (e.g., ground system documents) and did address a significant portion of the capabilities of each element providing Terra flight operations support.

Unfortunately, other levels of testing were also affected. Element system development often suffered from poor configuration management practices and some inconsistent interpretations of ambiguous requirements. The EOC systems were redesigned radically, but the requirements governing their functions were not revised completely. All ground element participants became part of 'the team' supporting flight operations team tests. With the Terra flight operations team leading all the tests, the MRM's role became largely that of a test witness, as opposed to a test director. The lack of direct oversight of end-to-end data flows increased the potential that system problems could go undocumented.

The MRM maintained a paper system for recording verification statements, which were signed by element representatives. In some cases, previous element Acceptance Test results were cited as evidence of requirement verification, rather than independent test results. Overall, the critical evaluation and the criteria for assignment of statuses were less rigorous than those applied for later missions.

As the first EOS mission, it was expected that Terra ground system testing would involve growing pains. The excessive number of problems experienced was noted by many, and recommendations were bundled into a variety of lessons-learned packages, to be applied to Aqua testing. Some of these were:

1) Spacecraft and ground system organizations need to have clearly defined management chains, with individual roles and responsibilities understood within and outside of each organization. Communication between elements needs to be improved.
2) Requirements need to be unambiguous, testable, and consistent. Improved requirements management and maintenance are needed.
3) Configuration management of systems, schedules, and test data files is important and should not be done lightly. Configuration changes and data updates need to be communicated to all affected elements as soon as possible.
4) Realistic schedules are needed, so that plans based on them are believable and usable. Plans need to reflect system/functional availability dates.
5) Additional complex, end-to-end test scenarios are needed, using realistic operating procedures and high-fidelity data sources. A single test director is needed for such tests to ensure that resources and schedules across test groups are consistent, reasonable, and do not conflict.

To implement these lessons learned, a new testing approach would be needed for the upcoming Aqua mission. The MRM made the decision to examine a more systematic and rigorous technical approach and to adopt a different test management approach as well.

3. Uniting the Forces of Systems Engineering and Project Management

The MRM decided to assess the applicability of a systems engineering methodology, similar to that successfully used for developing spacecraft hardware and associated systems, for a mission readiness testing program. From this review, it was concluded that a systems engineering approach would provide the necessary framework and foundation for our revised mission readiness testing plan, and thus we incorporated many such principles into our testing program for Aqua. Moreover, we reviewed the ideas behind successful project management, and by melding the best practices of systems engineering and project management, we were able to define a new model for the Aqua mission.

Table 1. Salient Features of New Model

• Develop a comprehensive, testable set of requirements and gain concurrence of all the affected element managers • Use a rigorous approach (e.g., “Data Threads”) to identify and trace the numerous data product flows through the various interfaces • Review the operations concept thoroughly ; design and conduct tests with on-orbit operations in mind; track test versus operations configurations • Establish an independent mission readiness team to assess and report actual system readiness and to identify and track readiness issues

The International Council on Systems Engineering (INCOSE) defines systems engineering as “an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and the required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem.” Furthermore, “systems engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.”

We began our technical activities by focusing on specific Aqua functionality and interfaces that would drive our test requirements, with an eye on the end-to-end operational system. Early on, we worked closely with the various ground system element managers and the Aqua FOT to develop a set of mission readiness requirements and to ensure that they understood our test goals and objectives as well as the need to become active participants and team members in our overall testing program. Finally, to ensure that this approach would work, we enlisted senior management’s support for this alternate model. This enabled us to establish and maintain a strong measure of independence while developing, executing, and documenting this alternate mission readiness testing model. The next few sections describe in more detail the results of our implementing this alternate testing model for the Aqua and ICESat missions.

4. Implementing the New Mission Readiness Test Model for Aqua

The shortfalls of the Terra mission readiness test model influenced heavily our decision to have a more active Mission Readiness Test Team (MRTT) be responsible for testing the Aqua ground system. In addition, we needed a team that could take a more proactive, independent approach. This section details how we applied key principles from both the systems engineering and project management disciplines to the Aqua test model, resulting in the successful Aqua test program (and beyond).

4.1. Defining and Documenting Requirements

Important aspects of successful systems engineering for complex systems include understanding objectives and conducting rigorous requirements identification, analysis, and management. In an ideal world, requirements flow down from an operations concept document, to ground system, spacecraft, and instrument specification documents [1]. The MRTT would then use the ground system document to develop the specific test requirements for verifying the readiness of the ground system to support launch and early-orbit operations, thus enabling complete traceability forwards and backwards. Unfortunately, good requirements traceability and testability did not exist for the Aqua mission due to lack of rigor in the development of the Aqua ground system document.

Convinced of the importance of having a solid set of test requirements, the Aqua MRTT expended a significant amount of time and effort on the requirements analysis phase. We drafted an initial set of Mission Readiness Test Requirements (MRTRs) based upon a thorough review of the Project documentation that was available at the time, including the Mission Operations Concept Document, Ground System Requirements Document, and various Interface Control Documents. The MRTRs were then documented in the Aqua Mission Readiness Test Plan (MRTP) [2] and widely circulated via email and web access [3] for analysis and updates from the ground system element managers.

A systems engineering focus on missions operations emphasized the importance of concentrating on performance requirements as well as basic functionality. As additional satellites are supported by the EOS ground system, the elements’ and networks’ abilities to sustain the increasing data processing loads must be proven prior to each launch. For Aqua, it was determined that single mission tests would not be adequate for all interfaces, so performance MRTRs were developed and multi-mission data loading tests were considered where feasible. In addition, error checking and high-volume data processing stress tests were known to be valuable, but the creation of special test data configurations and test data files requires a great deal of time and effort. These specialized tests can expose problems that would otherwise not surface until late in the testing or even during operations. On Terra, inadvertent data mistakes and inadvertent operator manipulations generated more error conditions than any set of test cases designed to test error handling capabilities of the systems under test.

Once we had a draft set of MRTRs specifying all the functions that were within the scope of our testing program, we conducted two analyses that helped to clarify and finalize the MRTR set. The first was a simple pairing of "send" and "receive" requirements. For each MRTR specifying that Element A send a data item to Element B, there would be a separate, consistent MRTR for Element B to receive that data item from Element A. The reason for having two requirements for one interaction is that the test team needed to be able to assess system statuses independently, since often only one side of an interface fails.

Next, to address issues of end-to-end mission perspective, we conducted a "thread analysis" of the mission data flows. Data flow threads represented the end-to-end flow of a single data item through the nodes of the integrated ground system. Each data item was traced from an original sender through one or more intermediate nodes until it either reached the final receiver or was changed significantly into a different data item (at which point a new thread was started). Due to the large number of Aqua requirements and the complexity of the EGS, the Thread Analysis proved to be rather time consuming; however, several previously undocumented requirements were uncovered which allowed early resolution of system design shortcomings.

Another area of systems engineering that we applied was the identification of high risk areas as early as possible in the program. During our requirements discussions with the element managers, we paid particular attention to those requirements that involved new or complex interface implementations, implying a high or significant risk from a testing and operational standpoint. These risks were documented and forwarded to the Project for on-going risk mitigation.

The process to develop a comprehensive, testable, and accurate set of Mission Readiness Test Requirements was a time-consuming effort. Requirements traceability was not as straight forward as was hoped, so to compensate, the team maintained close coordination and communication with each Element of the ground system throughout the development process. This enabled the team to continuously update the MRTRs to ensure they remained an accurate up-to-date reflection of the operational system. As launch readiness reviews were conducted, it became apparent that several dozen MRTRs did not have traceability to upper level documents. The missing traceability was, in fact, due to functionality missing in the higher level documents. The MRTT's methodical systems engineering approach used all levels of documents to develop its comprehensive set of requirements, especially the Interface Control Documents, operational agreements, and lower-level requirements specifications. The experience and vast systems knowledge of each member of the test team were key to verifying the Aqua ground system for launch.

4.2. Exercising Good Project Management Skills

The most important skills that were injected into the Aqua model included the following:

- Strong leadership throughout the test team
- Team-building principles to develop a high-performance test team
- Inclusive, "open" environment
- Frequent communications

Based upon the comments from the post-Terra review, we made a concerted effort to improve our working relationships with all ground system elements and to foster an environment of teamwork. To that end, we concentrated on improving overall communications, both written and oral, among all element managers and the FOT. Our first initiative was to get early concurrence on MRTR definitions, test constraints, and detailed success criteria from the element managers. We conducted in-person, early reviews with element representatives to define, finalize, and agree on all mission readiness test requirements, in order to permit testing to start as soon as various capabilities became available. Early element concurrence on the MRTRs was essential to support a common understanding of what was expected (for functionality and performance) and how requirement success or failure would be evaluated.

To foster an inclusive environment, we held bi-weekly MRTT working group meetings with all test team members to discuss topics related to upcoming tests. These MRTT working group meetings were held early in the ground system development cycle, to support test development and to identify potential issues early in the test planning cycle. This was important to the MRM who was now in a better position to identify elements that were behind in their development deliveries and to potentially gain insight into data paths that could not be exercised until very late in the test schedule. At these meetings, we strived to resolve any issues quickly and satisfactorily, working very closely with the element managers.

Our desire to establish an independent posture throughout the testing program was mentioned previously. An independent perspective was necessary to ensure the integrity of the test data, system processing, 'operational' approach, and test results. Furthermore, we felt strongly that an independent, "big-picture" perspective would keep the test team focused on performing tests correctly, not quickly, and conducting tests under the most realistic, operational conditions possible. Also, this independence allowed us to look for any "gaps" in the overall Aqua end-to-end test program conducted not only by us but also by other groups, the FOT for example. Key to this independence was maintaining an unbiased assessment of the current requirement status, which was vital to maintaining trust in the test reporting and verification process. Although challenged at times to lessen our independence, we relied on strong leadership from within the test team to resist these attempts.

4.3. Verifying the Ground System Functionality

Once the MRTRs were well defined and documented, test scenarios that contained progressively more complex ground system operations were defined and reviewed by the element managers. After a thorough review, the test scenarios were also documented in the MRTP [2] and served as the basis for developing the actual mission readiness tests to be executed. Key of course to a successful test program was the actual execution of the scenarios to verify the functionality and performance of the ground system in question. The following describes some observations about our testing approach that ultimately had a strong bearing on why we were so successful. First of all, we developed a suite of tests that at a minimum provided coverage for all of the launch critical requirements. Our test program consisted of twelve tests that ran the gamut of simple "point A to point B" data flow tests to a full-blown, integrated systems test incorporating all of the ground system elements that would be necessary to operate the Aqua mission (see Figure 1 for a graphical depiction of this test).

Second, as our test schedule allowed, we tried to "test early, and test often." However, any decision to run the test 'early' depended upon the specific capabilities missing, how soon they were expected to be available, and the benefits to be gained from a partial test run. Running a test too early could lead to a non-productive use of element resources and running a test too late might not allow a sufficient recovery time should serious problems be uncovered. However, before we began any serious mission readiness testing, we met with the element managers to ensure that system-level testing and acceptance testing had been conducted for their particular element; otherwise, the tests might fall short in attempting to verify functionality. For example, during our testing of the Ground Network sites, some of our Aqua MRTs turned into unplanned engineering/system-level tests, involving more system and human resources than necessary. All interface testing should be completed prior to MRTs to verify the data product and data transfer conformance to the Interface Control Documents (ICDs).

Another important success factor was the early definition and availability of good test data. Telemetry and data handling tests, especially those involving the Space or Ground Networks, are only as good as the test data being used. We strived to obtain realistic data early, to validate and document the contents, and to deliver files to each element for test use. Actual spacecraft data sets were essential for testing some elements of the ground system under operational conditions. Early spacecraft data had limitations. With each database change by the spacecraft or instrument developers, the data became out of date and less useful for detecting data path anomalies, because of format or mnemonic limit changes in the database. Early database updates tended to be more extensive than those close to launch. Real data was obtained from the spacecraft vendor as soon as possible after database updates to help minimize such problems.

Demonstrating repeatability was critical to validating the ability of the ground system to support mission operations. We also attempted to ensure sufficient time in the test schedule for late regression testing. This became particularly important around the ground system 'freeze' date. Probably the only time testing can occur on the real, to-be-flown ground system configuration is after Ground System "freeze", so we planned on having extra time in our schedule for last-minute tests.

We never assumed that any hardware or software change was "transparent." Software and hardware changes almost always affect previously-tested functionality, so we insisted that all changes to ground system elements' hardware, software, and configurations be reported to the MRM and closely tracked and assessed by the MRTT for potential impact to previous, current, and future testing. It was especially important to have a strong process in place to inform the MRTT of all changes to key ground network and space network configurations and other NASA institutional capabilities. Failing that, we would have been back in the Terra environment where changes were made without the proper procedures in-place to track them.

Lastly, an important process that we adhered to was the documentation of Discrepancy Reports (DRs) against all anomalies, not just major ones. We assigned an MRTT member to write each DR found during testing: too often a problem written by the developer did not include the specific problem found by MRTT and did not specify that the problem was found during an MRT. It was also important to retain artifacts to support the discrepancy analysis. In addition, we maintained an

MRTT independent presence on the Review Board to ensure that MRTT-generated DRs received proper attention and disposition. Finally, we made sure that adequate testing was done prior to closure of each DR. It should be noted that some conflicts did arise when an element assigned a status to a requirement that did not agree with the observations of the MRM or the other test engineers. Since the elements had been given the responsibility to status their own requirements and maintain their own artifacts, these situations were sometimes difficult to resolve and resulted in a requirement status of 'Open' being recorded while the issue was investigated further. But, having an open, cohesive team environment in-place significantly reduced any major disagreements between the MRTT and element manager.

5. Application of the Aqua Mission Readiness Test Model to the ICESat Mission

ICESat (the Ice, Cloud, and Land Elevation Satellite) was another EOS mission that used many of the same components as Aqua, but also gave responsibility for large parts of ground system to the spacecraft developer. The ICESat mission was a smaller mission (single instrument) with a correspondingly smaller test team. Several EOS Ground System components that support Terra and Aqua also provided ICESat support (spacecraft communications, data transport and processing, etc.). The main complicating factor was that the ICESat control center and flight operations team were located remotely from GSFC, as part of the Laboratory for Atmospheric and Space Physics (LASP) University of Colorado, and were operated under a contract to Ball Aerospace.

Ground systems test preparations for ICESat were nearly concurrent with Aqua test efforts, so the test planning and test management principles previously discussed that were applied to improve the Aqua mission readiness test effort were also applied to the ICESat effort. The mission readiness test team operated as an independent entity, monitoring the progress of ground system elements and reporting directly to the project on testing progress. MRTT meetings tended to cover a broad range of topics, functioning as more of a testing and operations working group and fostering a regular and beneficial exchange of information among all ground element representatives.

Mission Readiness Test Requirements (MRTRs) were developed from the ICESat Mission Operations Requirements Document and from knowledge of the participating ground system capabilities. The MRTP [4] was developed with test scenarios similar to those conducted for Terra and Aqua, but with modifications for different instrument and science data flow interfaces.

ICESat mission readiness testing was characterized by both hands-on testing of ground system elements and "outsourced" testing. The MRTT performed active testing of the ground system elements and interfaces, and the Mission Readiness Test Engineers occasionally observed in a passive role when LASP conducted internal readiness tests and simulations. During multi-mission tests with other, higher-visibility EOS missions, ICESat test objectives were not the drivers of the test scenarios but were fully included. Close cooperation and persistence were required to ensure that this happened.

Tests were conducted as early as feasible. Early science system tests were run as partial test cases, using the early versions of science data processing systems, as a way for the MRM to get an early indication of element readiness and for the system developer to 'acceptance test' their system in a semi-operational environment. These tests helped identify basic interface and system problems while it was still easy to implement fixes.

Sometimes, testing results surprised the participating elements – ICESat data rates and complexity seemed low relative to other larger missions, yet almost every test found something that needed to be fixed, and in a few cases called for new code. In all aspects, the principles that were developed for Aqua testing and applied to ICESat were proven to be effective and useful. The successful application of these principles to the ICESat mission also demonstrated that the guidelines and processes necessary for testing very complex missions (e.g., Aqua) are scalable and are important for complete testing of smaller and less complex missions such as ICESat.

6. Challenges Remain for Aura Mission Readiness Testing

Despite the successes achieved during the mission readiness testing for the Aqua and ICESat missions, several challenges remain for the upcoming Aura mission (scheduled for an early 2004 launch). Although the spacecraft and ground system are very similar to that used for Aqua, the requirement remains to fully test the ground system within a multi-mission environment. Also there is a strong desire to test the overall performance during data "outages" and hence test the resiliency of the ground system to recover to nominal data processing operations.

As mentioned in the Introduction, the EGS will be generating 350 billion bytes of Level-0 science data per day from all four satellites. The challenge for the Mission Readiness Test Team is to develop and execute a series of anomaly tests (within an existing operational environment!) that will generate a series of detailed metrics that can be used to assess how the EGS will react to a failure of one or multiples of the ground system elements. The results of these tests could be useful in determining where the "chokepoints" are and where the insertion of additional backup capabilities might be needed.

Even though Aqua MRT was performed in an operational environment, there was only one spacecraft on-orbit (Terra). Now that Aqua and ICESat have joined the science data gathering community, there are significant time and resource restrictions imposed on testing. For instance, during Aqua, MRT could request a Ground Station support of EOS resources for a 4 hour block of time. Now, Aura must utilize EOS Ground Station resources in 1 hour blocks sandwiched between Aqua and ICESat Science data dumps. Additional test planning and coordination is required to prevent any potential conflicts between the test effort and on-orbit operations.

Another challenge is to perform a series of regression tests on the telemetry and command software that will be delivered to support the Aura mission. For the Aqua mission, considerable effort was expended in testing the major functionality of the software, and the test team gained significant experience in this area. However, in the future, they will not only have to test the new software required for the Aura mission, but will have to ensure that existing functionality is not compromised with the latest Aura release. This will require an in-depth knowledge of the telemetry and command software and how the existing system operates today.

Programmatic challenges remain for Aura MRTT. Although budgets always impose constraints on projects, and are particularly tight on testing activities, Aura, being the last of the three planned EOS missions has an especially tight budget. The Mission Readiness Test Team has, and must continue to, look at ways to streamline the tests while providing the necessary level of completeness and attention to detail to ensure another successful test campaign. As Aura Project Management decisions influence the scope and breadth of testing, it is the MRTT's responsibility to identify, evaluate, and inform management of potential risk areas.

Many EOS contracts phase down as Aura launch approaches and then terminate or transition to new contracts after launch. With the current tight job market persons are anxious to ensure their job security. This may lead to experienced members leaving for other opportunities. Steps need to be implemented before individuals 'move on' in order to maintain the system knowledge base and the processes/procedures that enabled the MRTT to be so effective on Aqua.

In addition to the attrition of 'hands-on' persons, changes in management are occurring within contractors and at the GSFC. New management brings new experiences and concepts of how to conduct effective testing. Providing new management with lessons learned [5], and establishing regular meetings to communicate current status and discuss previous experiences will help to ensure a smoother transition.

7. Concluding Remarks

The revamped mission readiness test program for Aqua was highly successful. All major functional and performance criteria were met, and only a small number of ground system anomalies were reported (compared to Terra!) during on-orbit operations, and those that did occur were fixed very quickly. In our opinion, the rock-solid performance of the EGS to date has validated our mission readiness testing model and our approach for implementing it. Several conclusions can be posed at this time:

1) The systems engineering methodology can be successfully adapted to a mission readiness test program
2) Adhering to core project management guidelines created the necessary environment in establishing a cohesive test team
3) Investing the effort and schedule into developing a strong requirements base was rewarded;
4) This new testing model proved to be scalable (for example, ICESat), and
5) Maintaining an independent posture while at the same time fostering teamwork created the right environment for testing a ground system as large and complex as the Aqua ground system.

8. References

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